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16. ABSTRACT
Results of laboratory and field tests are presented which show the effects of various compactive efforts on unit weight, yield, and cement factor of fresh concrete.

The data indicate that while some increase in density (approximately 0.5%) can be obtained by using compaction methods other than the standard rodding, the unit weight test as described in ASTM Designation C 138 (Test Method No. Calif. 518), is the most practical and realistic method of determining yield and cement factor.

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DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
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July, 1967

Research Report
M&R No. 635148-1

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

A STUDY OF
UNIT WEIGHT, VOLUME, AND CEMENT FACTOR
OF FRESH CONCRETE

Donald L. Spellman
Principal Investigator

Wallace H. Ames
and
James H. Woodstrom
Co-Investigators

Very truly yours,

JOHN L. BEATON
Materials & Research Engineer

67-02

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The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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A STUDY OF UNIT WEIGHT, VOLUME, AND CEMENT FACTOR OF FRESH CONCRETE

INTRODUCTION

Since 1939, ASTM Designation C 138 has been the accepted test method for determining the weight per cubic foot of freshly mixed concrete, the volume of concrete per unit volume of cement, the actual cement factor, and the air content (gravimetric) of concrete. This method is probably the most practical method of determining the volume of structural concrete delivered to the job. With the advent of slipform paving and elimination of side forms, the method became widely used for determining the amount of paving concrete produced per batch. Test Method No. 518, "Method of Test for Unit Weight, Volume, and Cement Factor of Concrete" was adopted by this State in 1956 and became a part of our concrete specifications. The California test method is a slight modification of ASTM C 138, and contains no reference to air content.

At times, questions have been voiced by Contractors and others concerning validity of the test method. It is their contention that consolidation of concrete by vibrators and placing machines is greater than that provided in the unit weight test by rodding. Since the cement factor is adjusted on the basis of unit weight tests, some contractors felt they were being penalized by having to add more cement due to the alleged lesser weight of the rodded concrete. Some estimates of this loss were as much as 2%, or approximately 0.1-sack of cement for every cubic yard of concrete.

This report covers a recent study made by the Materials and Research Department to develop information relative to the application of the unit weight test. The study consisted primarily of two parts: (1) a comparison of unit weights using various methods of consolidation, and (2) a comparison of unit weights of paving concrete sampled ahead of and behind a paving machine.

Since some misunderstanding was found to exist concerning the intended application and limitation of the unit weight test, a discussion of the test, its purpose, and proper use with respect to the design and control of concrete mixes is included in this report.

CONCLUSIONS

The following conclusions are based on the findings from the limited test program described herein, using various concrete mixes, compactive efforts, and field samples.

1. Large increases in the amount of vibration of concrete in the Unit Weight Test produced very small changes in the actual unit weight. Revibration of job concrete for 20 seconds with an internal vibrator following standard rodding (which would far exceed normal job vibration) produced an increase in unit weight of approximately 0.3%.

2. The variation in unit weight and calculated cement factor as determined from the unit weight tests taken in front of and behind a paving machine is very minor. On the two projects tested, the unit weight was found to average 0.5% and 0.4% greater when sampled behind the paving machine.

3. The long established system of using the unit weight test to determine yield and cement factor of concrete delivered to the work is the most practical and realistic method and is more accurate than any other system.

EFFECT OF DIFFERENT COMPACTIVE EFFORTS ON UNIT WEIGHT

One objective of this study was to determine the amount of variation in unit weight that might result from varying methods of consolidation. Preliminary unit weight tests were made with laboratory concrete using American River aggregates. Varying degrees of internal mechanical vibration were used to consolidate the concrete in the unit weight bucket and resulting unit weights were compared to those obtained in parallel tests on the same concrete, consolidated by rodding per Test Method 518. Even with internal vibration far exceeding that which would be obtained in the field, unit weight was increased only 0.5%.

Similar comparisons were then made in the field on job concrete. Two test series were completed on jobs in the San Diego area and one in the Sacramento area. The San Diego area was selected because the local aggregates make harsh, unworkable concrete which is difficult to consolidate.

The testing program was undertaken using three unit weight buckets and running three tests simultaneously from a single sample of about 2-1/2 cubic feet of concrete. The concrete was sampled in a large sampling pan 30"x30"x6" deep, and was remixed with a shovel before testing. The air content was determined, followed by the three unit weight tests made simultaneously. The unit weight buckets were filled a layer at a time, alternating between the three buckets. One bucket was rodded in the standard manner. The second bucket was vibrated two to three seconds per layer with a single insertion of a 1-inch electric vibrator. The third bucket was vibrated "excessively" by inserting the vibrator at various locations a total of ten times in each layer for two to three seconds for each insertion. The concrete was struck off in the usual manner and unit weights were determined.

Following the initial unit weight determinations, all three samples were "revibrated" by a single insertion of the vibrator full depth for approximately 20 seconds. Concrete was added to the bucket to replace any lost as a result of the revibration process. The unit weight was then redetermined. Data from these tests are shown in Tables 1, 2 and 3. It can be seen that very little difference in unit weight was realized by the extreme variations in methods used for consolidating the concrete. The greatest differential occurred on Job No. 3 in which paving concrete (low slump) was tested. In Jobs Nos. 1 and 2, structure concrete was used having a higher slump than that used for pavement.

The revibration of rodded concrete in all three "standard test" series resulted in a maximum increase in density of only 0.3%. The 20 seconds of "revibration" in 1/2-cubic foot of confined concrete would be equivalent to about 18 minutes of vibration per cubic yard in job concrete, with the distance between vibrator insertions not exceeding 10 inches. Ordinarily, typical vibration of field concrete rarely exceeds two or three minutes per cubic yard.

These tests indicate that the claims of 2% greater densities and correspondingly smaller yields in job concrete are not valid. Results shown in Table 2 indicate that it is possible to get even less density with vibration than that obtained by "test procedure" rodding.

EFFECT OF SAMPLING AHEAD OF AND BEHIND PAVING MACHINE ON UNIT WEIGHT

In this part of the study, the effect of consolidation by the paving machine on the unit weight of the concrete was investigated. To achieve this, concrete of a given batch was sampled immediately ahead of the paving machine. The same batch was again sampled after the paving machine had passed over consolidating it with vibrators in the process. Air contents and unit weight determinations were made on the samples of concrete. Cores of the hardened concrete were taken from the same area and their unit weights were determined. A tabulation of the test data is shown in Tables 4 and 5.

Consolidation of the fresh concrete by the paving machine was found to increase the unit weight 0.8-pound per cubic foot on one project (Table 4), and 0.6-pound per cubic foot on the other (Table 5). The increase in unit weight corresponds to a volumetric reduction of 0.5% and 0.4% respectively, which is in excellent agreement with the measured volumetric reduction in air content of 0.5% and 0.6%, also in the same respective order. It thus appears that the loss of air content due to consolidation is the significant contributing factor in the relatively small change in volume that takes place. Evidently, once some of the entrapped or entrained air is removed by the paving machine, subsequent handling in the resampling process does not reintroduce lost air. However, it must be pointed out that the exact density of the fresh concrete in place in the pavement slab before resampling is unknown. The effect of remanipulation on test results is believed to be negligible, since both samples receive about the same amount during the test. In any event, the comparison of the unit weights of the fresh concrete ahead of and behind the paving machine is believed to be a valid measure of the effect of consolidation in the paving operation.

The unit weights obtained from 5-inch diameter cores from 5-sack concrete, show an increase of 0.9-pound per cubic foot (Table 4). The average unit weight of cores from the 6-1/2-sack concrete was only about 0.2-pound per cubic foot greater than that of the fresh concrete (Table 5). The standard method for determining the density of cores is the weight in air - weight in water method, after presoaking a minimum of 48 hours. In presoaking, the hardened concrete absorbs water resulting in an amount greater than that which was present in the plastic state. It is primarily for this reason that the measured densities of cores are higher than that of the fresh concrete. Other minor factors that may contribute to the differential are bleeding and settlement which tends to reduce the volume of the hardened concrete as compared to the volume of the fresh concrete.

DISCUSSION OF TEST METHOD FOR UNIT WEIGHT, VOLUME, AND CEMENT FACTOR

Test Method No. Calif. 518 is entitled "Method of Test for Unit Weight, Volume, and Cement Factor of Concrete." This test is often referred to as the "yield test", in spite of the fact that no mention is made of the term "yield" anywhere in the text of the test method. Yield is a term that means different things to different people. Concrete technologists usually know what one means when he talks about yield, but the following definitions have been widely used:

1. Yield is the volume of concrete per unit volume of cement (normally one sack), according to ASTM Designation C 138-63. (This appears to be the "official" definition, if not the universally accepted one.)

2. Yield is the number of cubic feet (volume) of concrete per batch.

3. Yield is the cement content per cubic yard of concrete.

4. "Relative yield" is the ratio of actual volume of concrete obtained to the volume as designed for the batch, also according to ASTM C 138-63. This ratio is sometimes referred to simply as "yield" in common usage, although the term "relative yield" is more descriptive and quite appropriate in discussing the problem.

In designing a concrete mix, the purpose is to obtain a "relative yield" as close to 1.00 as possible; that is, the actual volume of a "designed" cubic yard should be one cubic yard. If it were practical to accurately weigh all the ingredients designed to produce a cubic yard, mix thoroughly, and fill an accurate cubic yard measure, our relative yield determination would be fairly straightforward. If this resulted in a "long" or a "short" yard, adjustments to the mix design could be made to more nearly produce an exact cubic yard volume having the desired cement content. Since this approach is not practical, the "unit weight test" is employed to provide the necessary data for adjustments of mix design and corresponding batch weights. In effect, these two procedures are the same except that in the unit weight test, a small sample is used that is practical to handle.

Although the calculations in the test method are relatively simple, some individuals seem to read more into the test than is actually there. By following the test procedure, the unit weight of fresh concrete in pounds per cubic foot is first determined. The volume of concrete per batch and the actual cement factor of the concrete produced can then be calculated. In reviewing the calculations briefly, it is noted that only two factors need to be known to calculate the volume of the batch. They are:

(1) W = Unit weight in pounds per cubic foot (the net weight of concrete in the calibrated bucket times the calibration factor)

and

(2) Wt = the total scale weight of all the ingredients in the batch of concrete.

The volume, S, in cubic feet of concrete produced per batch is:

$$S = \frac{Wt}{W}$$

In other words, the total weight in pounds per batch of concrete, divided by its unit weight in pounds per cubic foot, equals the quantity in cubic feet. The important thing here is that the actual weights of the water, cement, and aggregates going into the batch must be used, not the "design" weights which are usually slightly different.

It is important to note that the unit weight test does not check batching accuracy. The Engineer or inspector must first be assured batching scales are accurate. One way this can be accomplished is by having the scales inspected and sealed by established authorities. Batching accuracy can be reasonably checked after scales are sealed by observing the batching operation and by requiring the contractor to determine the gross and tare weights on the mixer truck. This method should only be used as a rough check of batching accuracy, not as the value to use in the calculations of batch volume (see Section 90-5.03 of the California Standard Specifications).

When the unit weight test is to be performed, the actual batching of the load to be checked should be observed and scale weights recorded for use in determination of batch volume. The mixer drum should also be checked prior to batching to be sure that a significant quantity of water is not left in the drum and unaccounted for in batch weights. It is again pointed out that if scale weights are not accurate or if the exact weight of the cement entering the batch is not known, the subsequent calculations cannot be used to determine the cement factor. When the unit weight of the concrete, the actual weight of the cement, and total batch weight is known, the cement factor, CF, in sacks per cubic yard can be calculated by simple proportion as follows:

$$\left(\frac{CF}{27}\right) = \frac{N}{S} \quad \text{or} \quad CF = \left(\frac{27N}{S}\right)$$

Where N = number of sacks of cement in the batch

$$\left(\frac{\text{Wt. of cement}}{\text{94 lbs./sack}}\right)$$

S = volume of concrete produced per batch in cubic feet (determined from unit weight as described above)

That is, the cement factor in sacks per cubic yard is to 27 cubic feet per cubic yard as the number of sacks in the batch is to the number of cubic feet in the batch. Here it is seen that the number of sacks in the batch must be the actual amount of cement batched as determined by plant scales and converted to 94-lb. sacks. Weighing bulk cement, or counting sacks is the only way to know exactly how much cement is in the batch.

The application of this procedure is required by the California Standard Specifications, Section 90-1.01, which reads as follows:

> "Should the quantities of ingredients designed to produce a cubic yard of concrete result in a volume (yield) greater or less than one cubic yard, the amounts of coarse and fine aggregate shall be changed as necessary to maintain the constant quantity of portland cement in each cubic yard of concrete.

"The unit weight, yield, and cement factor of the concrete will be determined in accordance with Test Method No. Calif. 518."

There is nothing new about this approach to adjusting concrete mixes. The ASTM test after which Test Method No. Calif. 518 was patterned, was adopted in 1939. The early version of the test permitted mechanical vibration of concrete into the unit weight bucket, if mechanical vibration was used in the field. This was revised in 1944 and the rodding of three layers 25 times each, was adopted as the only allowable procedure.

In Publication No. 66, "Sampling and Testing Ready-Mixed Concrete" by the National Ready-Mixed Concrete Association (representing concrete producers), August 1964 edition, the following pertinent information is found under the heading "Yield":

"Ready-mixed concrete is purchased by the cubic yard. According to the "Specifications for Ready-Mixed Concrete", ASTM Designation C 94, the basic unit is 'the cubic yard of plastic and unhardened concrete as delivered to the purchaser.' The volume of a batch 'shall be determined from the total weight of the batch divided by the actual weight per cubic foot of the concrete. The total weight of the batch shall be calculated either as the sum of the weights of all materials, including water entering the batch, or as the net weight of the concrete in the batch as delivered. The weight per cubic foot shall be determined in accordance with the 'method of Test for Weight per Cubic Foot, Yield, and Air Content (Gravimetric) of Concrete' (ASTM Designation C 138). By definition, 'Yield' is the number of cubic feet of concrete produced per sack of cement, but popular usage applies this term also to the volume of concrete actually produced in a batch.

"Controversies over volume of concrete furnished can be minimized if the purchaser is aware of the standard method of measurement. He should understand that there may be some discrepancy between the volume delivered and the calculated volume of the forms. Concrete may lose volume slightly on hardening by loss of bleeding water or air, but this reduction is quite small. The largest errors result from difference between the assumed and real volume of the concrete in place. (Our underline.) "Even slight deflection of forms or irregularity of subgrade can account for an appreciable amount of concrete. An increase of 1/4-inch in the average thickness of a 4-inch slab, for example, results in the need for an extra cubic yard of concrete for each 16 anticipated."

Our specifications recognize, just as stated in the above quotation, that there will be minor discrepancies between the theoretical or calculated volume of the forms and the volume delivered, due to settlement shrinkage, slight undetected variations in water content of aggregates, specific gravity of aggregates, etc.

Variation in cement factor is reflected directly in the volume (relative yield) of concrete batched, assuming accurate batching of cement. Although our specifications state that a "variation of 2-1/2% or less, from the theoretical amount of cement required, will be considered as a normal expectancy in proportioning concrete", it does not mean that adjustments in batch proportions need not be made if calculations indicate we are within 2-1/2% of the specified cement factor. The average cement factor can be controlled well within these limits and should be close to the specified amount.

In view of the above discussion, there is no reason to doubt the validity of the long established procedure utilizing the unit weight test to determine the actual batch volume and cement factor of concrete. All those concerned with the control of portland cement concrete should become familiar with the procedure, purpose, and limitations of this test and take advantage thereof in maintaining the proper cement factor. It has been proven universally to be more accurate than any other practical system.

TABLE 1

Unit Weight Test Results

	Standard Rodding		Vibrated 2 Sec./Lyr		Excess Vibration	
	Initial	Revib. Addn'l 20 Secs.	Initial	Revib. Addn'l 20 Secs.	Initial	Revib. Addn'l 20 Secs.
Job No. 1						
Round #1 1.3% Air	147.9	-----	147.6	-----	147.4	-----
Round #2 1.5% Air	146.5	147.1	146.6	146.8	147.0	147.0
Round #3 1.3% Air	147.0	147.4	147.0	147.4	147.7	147.7
Average, Rounds 1,2,3	147.1	-----	147.1	-----	147.4	-----
% Variation from Standard Test	0.0%	-----	0.0%	-----	+0.2%	-----
Average, Rounds 2,3	146.8	147.3	146.8	147.1	147.4	147.4
% Variation from Standard Test	0.0%	+0.3%	0.0%	0.2%	+0.4%	+0.4%

TABLE 2

Unit Weight Test Results

	Standard Rodding		Vibrated 2 Sec./Layer		Excess Vibration	
	Initial	Revib. Addn'l 20 Secs.	Initial	Revib. Addn'l 20 Secs.	Initial	Revib. Addn'l 20 Secs.
<u>Job No. 2</u>						
Round #1 0.6% Air	147.0	147.0	147.0	147.0	147.5	147.5
Round #2 1.0% Air	147.5	-----	146.0	-----	147.8	-----
Round #3 0.7% Air	<u>147.0</u>	<u>147.0</u>	<u>147.1</u>	<u>147.3</u>	<u>147.0</u>	<u>147.3</u>
Average, Rounds 1,2,3	147.2	-----	146.7	-----	147.4	-----
% Variation from Standard Test	0.0%	-----	-0.3%	-----	+0.1%	-----
Average, Rounds 1,3	147.0	147.0	147.1	147.2	147.3	147.4
% Variation from Standard Test	0.0%	0.0%	+0.1%	+0.1%	+0.2%	+0.3%

TABLE 3

Unit Weight Test Results

	Standard Rodding		Vibrated 2 Secs./Layer		Excess Vibration	
	Initial	Revib. Addn'l 20 Secs.	Initial	Revib. Addn'l 20 Secs.	Initial	Revib. Addn'l 20 Secs.
Job No. 3						
Round #1 1.1% Air	156.7	157.0	156.1	157.2	157.0	157.5
Round #2 1.1% Air	155.2	155.8	156.0	157.1	157.0	157.5
Average	156.0	156.4	156.1	157.2	157.0	157.5
% Variation from Standard Test	0.0%	+0.3%	+0.1%	+0.8%	+0.6%	+1.0%

TABLE 4

Fresh and Hardened Concrete Test Results
5 Sacks Cement per Cubic Yard

Test	Ahead of Paver[1]		Behind Paver[2]		Hardened Concrete[3]
	Air %	Unit Wt. Lbs./CF	Air %	Unit Wt. Lbs./CF	Unit Wt. Lbs./CF
1	2.2	151.2	1.9	152.6	152.9
2	2.5	152.5	1.9	153.6	153.7
3	2.4	151.6	1.8	152.8	152.8
4	2.5	150.4	1.9	152.6	154.1
5	2.5	152.9	1.8	152.8	153.9
6	2.6	153.3	2.1	151.8	153.8
7	2.2	152.7	1.9	152.5	154.1
8	2.6	154.0	2.2	153.2	153.7
9	2.6	151.3	2.2	152.3	152.1
10	2.1	153.0	1.7	154.1	155.4
11	2.7	150.8	1.8	152.5	153.4
12	2.7	150.9	2.4	153.0	154.1
Avg.	2.5	152.0	2.0	152.8	153.7

[1]Taken from paver hopper

[2]Taken from pavement immediately after paver passed and about 3 feet from median edge

[3]Cores obtained from hardened pavement 6 feet from median edge. (Center of Left No. 1 lane.)

TABLE 5

Fresh and Hardened Concrete Test Results
6-1/2 Sacks Cement per Cubic Yard

Test	Ahead of Paver[1] Air %	Ahead of Paver[1] Unit Wt. Lbs./CF	Behind Paver[2] Air %	Behind Paver[2] Unit Wt. Lbs./CF	Hardened Concrete[3] Unit Wt. Lbs./CF
1	7.0	141.4	5.0	144.6	145.1
2	4.5	147.0	3.9	147.2	146.2
3	4.2	147.2	3.5	146.4	146.5
4	5.0	144.6	3.9	145.7	146.9
5	3.5	147.6	3.3	147.6	146.6
6	3.2	147.2	3.0	148.8	150.0
7	4.8	146.6	4.3	147.0	145.3
8	6.0	143.6	4.9	145.4	146.8
9	3.6	147.2	3.4	148.0	148.1
10	3.8	146.4	3.5	146.7	146.7
11	1.3	149.6	1.3	149.4	150.6
12	4.4	144.8	4.3	144.0	144.4
Avg.	4.3	146.1	3.7	146.7	146.9

[1]Taken from paver hopper

[2]Taken from pavement after paver passed and about 2 to 3 feet from ourside edge (Lane 2)

[3]Cores taken 4 feet from outside edge of pavement